AFRL-IF-RS-TR-2003-188
Final Technical Report
August 2003

COMMAND, CONTROL, COMMUNICATIONS, & INTELLIGENCE (C3I) SYSTEMS ANALYSIS AND TRADE-OFFS

CACI Technologies, Incorporated

AIR FORCE RESEARCH LABORATORY
INFORMATION DIRECTORATE
ROME RESEARCH SITE
ROME, NEW YORK

This report has been reviewed by the Air Force Research Laboratory, Information Directorate, Public Affairs Office (IFOIPA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be releasable to the general public, including foreign nations.

AFRL-IF-RS-TR-2003-188 has been reviewed and is approved for publication.

APPROVED: /s/
ROBERT M. FLO
Project Engineer

FOR THE DIRECTOR: /s/
JAMES A. CUSACK, Chief
Information Systems Division
Information Directorate

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 074-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	AUGUST 2003	Final Mar 01 – Jan 02

4. TITLE AND SUBTITLE
COMMAND, CONTROL, COMMUNICATIONS, & INTELLIGENCE (C3I) SYSTEMS ANALYSIS AND TRADE-OFFS

5. FUNDING NUMBERS
C - F30602-00-D-0221/Task 3
PE - 62702F
PR - 558B
TA - QF
WU - 05

6. AUTHOR(S)
Jack Mineo

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
CACI Technologies, Incorporated
14151 Park Meadow Drive
Chantilly Virginia 20151

8. PERFORMING ORGANIZATION REPORT NUMBER
N/A

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory/IFSB
525 Brooks Road
Rome New York 13441-4505

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
AFRL-IF-RS-TR-2003-188

11. SUPPLEMENTARY NOTES

AFRL Project Engineer: Robert M. Flo/IFSB/(315) 330-2334/ Robert.Flo@rl.af.mil

12a. DISTRIBUTION / AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 Words)*
An analysis of on-going and planned Air Force (AF) programs was completed leading to a proposed baseline design of an AF C2ISR System. The project included a review of the difficult Time Critical Target threats and the operational concepts as outlined in the AF Global Strike Task Force design structure. The applicability of the technology was outlined to address this difficult operational problem.

14. SUBJECT TERMS
Time Critical Targets, C2 System Analysis, ISR Fusion and Planning

15. NUMBER OF PAGES
28

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

Table of Contents

List of Figures

List of Tables

Overview

This report presents the results of a system analysis of many of the AFRL/IF programs that support target engagement under the banner of Sensor to Decision-maker to Shooter. Some of these programs cut across AFRL directorates, are funded by multiple sources and have joint service and coalition partner involvement . The analysis also included a review of the current threat and architecture issues being flagged by Air Force as important to warfighter capabilities. The analysis focused on meeting current needs as well as outlining technical design difficulties, and transition opportunities.

The AFRL/IF has done an excellent job in gaining support and funding for key programs Strong partnerships have been established across the Air Force, Joint and Coalition communities, putting AFRL/IF in a great position to make significant technical contributions leading to a fully compliant fielded capability.

This report summarizes key program findings and Recommendations.

1.0 Introduction:

The objective of this task was to perform system tradeoff analysis of information technologies for Air Force integrated C2ISR systems, with a specific focus on Time Critical Targeting. The details outlined in this report provide some insight into tasks performed. In many cases, the interaction with program offices were in much more depth on problems at hand as well getting program managers to work together towards a common goal. The analysis completed included a review of ongoing Air Force initiatives, coordination of joint Air Force/DARPA/OSD initiatives and recommendation of responsive programs. These programs were based on concepts that met user needs by leveraging ongoing government and commercial technologies.

The difficult challenge is based on integrating Intelligence, Surveillance, Planning and Weapon sub systems into a integrated Command & Control Intelligence, Surveillance & Reconnaissance system responsive to time sensitive threats such as moving or pop up targets. This system must not only provide an integrated picture of the threat but also portrayed to allow rapid decision making and then rapid execution using available weapon targeting systems. This complex system of systems challenge requires close coordination of all assets in a common infrastructure framework. This is difficult as many of these sub systems were built to perform their unique functions in a specific infrastructure or operating environment e g: Intelligence. In order for these systems to interact arbitrary forced information bridges must be constructed. These bridges do not leverage the flexibility in the individual sub systems but at best use their output products efficiently.

The TCT problem needs close integrated operations of all these sub systems to allow all source detection and tracking, interface and handoff off information to planning and decision process leading to timely execution of missions to counter the threats. The difficulty not only lies in the difficult initial detection process of hidden time sensitive targets, but also what to do with these detection's, in light of planned mission objectives and aircraft weapon payload status. The key is "time sensitive targets" which set up the timeframe for effective reaction. If the targets can be counter or negated outside this time frame then the standard planning execution process can be employed. However, if countering the targets within a specific time is critical to allow effective warfare then the problem gets very difficult as all sub systems must interact efficiently. This coupling requires a well-defined and effective Sensor to Decision-maker to Shooter framework. The sensor piece consists of fused Intell-Surveillance-Reconisance (ISR) function, which integrates target, cues, detection and images into an operational picture.

2.0 Challenge Problem

As outlined above, a review of the current TCT situation reveals a significant design problem that requires a thorough systems engineering based approach to optimally manage the operational AF theater assets in a “Sensor-to Decision Maker - to Shooter” framework to meet ATO planned and TCT unplanned activities. The primary issue in the TCT problem is the time factor. The time factor issues are as outlined by the SAB in Figure #2-1 below. This figure compares the current response time (NOW) with future operational requirements (FUTURE). Recommended CHANGES to the NOW system to meet FUTURE requirements are also shown. The SAB set up the case per following:

"Recent conflicts have highlighted the difficulties in rapidly attacking TCTs. The timelines from recognition of the existence of a targetable object until the "kill" is excessfully long. Experience in Operation Desert Shield, Storm and Operations Noble Anvil (in Kosova) showed that timelines of 4+ hours were typical. The goal expressed by the leadership is to reduce the time from target detection to target strike to single digit from current multiple hours."

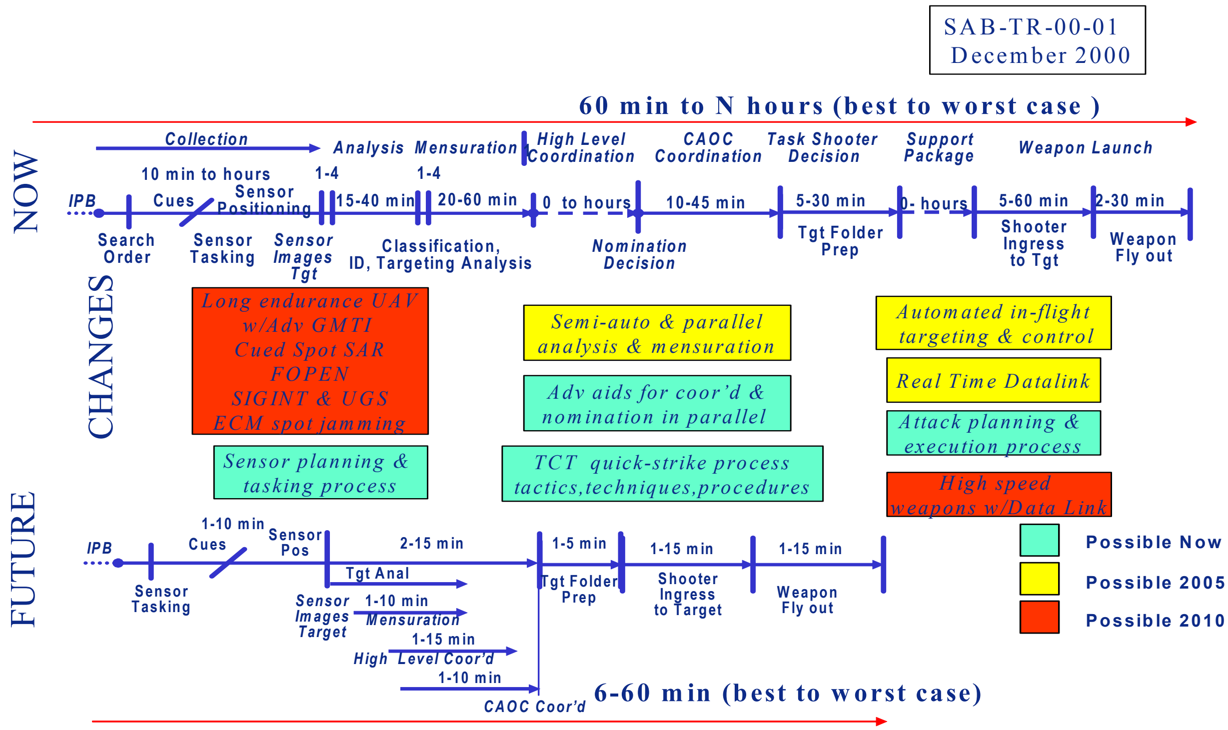


Figure 2-1 TCT Targeting Timeline Now and Future

The TCT challenge and technology needs must also be examined in terms of the Global Strike Task Force concept as defined by ACC General Jumper. Figure 2 -2 below details some of the tenants of GSTF which are base on minimum deployment Expeditionary Air Force to rapidly kick the door down and reduce force presence. This chart was derived by General Jumper to outline this approach. It essentially outlines operations used during most of the recent military operations.

Technology Integrating Needs

Figure 2-2 Technology Integrating Needs

General Jumper continues in this presentation to detail technology needs to enable this approach and states they are based on:

- Predictive Battlefield Awareness
- Assured Global/Theatre Networking & Communications
- Global/Theatre Planning & Execution
- Integrated ISR Operations and Targeting

Combining the TCT Time Constraint issues with the quick reaction limited footprint operations as defined in GSTF provides a difficult technical challenge. The systems and subsystems must be well structured and information flow must be integrated to provide on time capabilities worldwide. These challenges as a minimum are as follows:

- Distributed Effects Based Planning & Execution
- Remote Distributed Decision Making
- Enroute Replanning/ Reachback
- Worldwide PBA
  - Rapid Integrated ISR Updating
- Validated Targeting
  - ISR Integration
  - Integrated Assured Ops(Sensor-Dec Maker Shooter)
- Rapid Assessment For Assured Ops

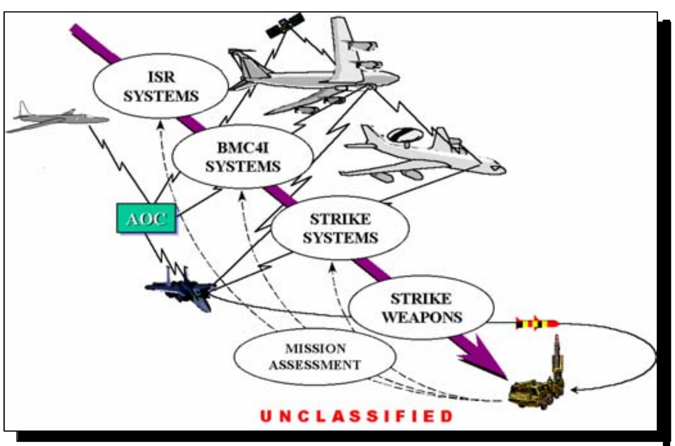
3.0 Program Reviews

The work performed under this task included reviewing the above challenge problem in light of ongoing AFRL/IF programs and their connection to users needs as well as other ongoing initiatives. Outlined herein is a representative sampling of these programs and the impact to addressing above goals. The issues will be synopsized later into key program and technology thrusts.

3.1 Sensor to Decision-Maker to Shooter

(SDMS) The starting point for the review was an analysis of the problem and proposed (SDMS) program. The program contended that the Future Conops would be driven by standoff capabilities of precision weapons. Further data links on weapons that allow remote weapon tasking/retasking and direct BDI and ISR cueing for BDA. It makes the case by outlining the B1/B2 weapons loading capabilities enhanced by advanced weapons capabilities of systems like Locaas. A recognition was made of the current C2 environment (TACS) and the need for improved operations using a Time Critical Targeting cell which integrated ISR data with Operational plans, targeting and terrain analysis to enhance ops against time critical/sensitive targets! This program initiative did a good job of categorizing ongoing initiatives across the AFRL labs as well as establishing proposed joint activities and the following well-founded operational objective:

Real Time Sensor-to-Shooter Operations



Capabilities

Seamless Near Real Time Operation between Sensors, Commander, Shooters, and Weapons

- **Near Real Time F2T2E & A for Time Critical Targets**

Technologies

- **Real time Information Fusion in and out of the cockpit and in cockpit route planning**
- **Real Time Targeting, Mission Planning, Replanning and Command Loop**
- **Real Time Weapons Interface for Damage assessment**
- **Human Interface**

Goal

- **Near Real time operation between sensors, decision maker(s), shooters, and weapons to address time critical targets**

Figure 3-1 Real Time Sensor-to-Shooter Operations

"Exploit, Demonstrate, and Integrate Information and Human Interface technologies with ISR Sensor and Weapon technologies to provide <u>real time</u> fused sensor and tasking feeds from decision makers to shooters and/or weapons to Find, Fix, Track, Target and Engage (F2T2E) time critical targets with the right response on the right target at the right time and provide instantaneous damage assessment to the commander"

The initiative then attempted to show how the above technologies and processes that could be demonstrated via simulation and testing as outlined in functional system diagram as outlined in figure #3-1. All of this was very reasonable and could lead to a strong foundation for the F2T2E problem once all the critical issues were factored with ongoing technical program areas as detailed in the proposed program. The initiative then outlined the contributions of each participating Directorate based on many ongoing and planned programs. The overview of each directorate was based on their technical expertise as follows:

IF- C2 Decision Making & Targeting, Tasking & targeting
- Joint Defensive Planner (JDP)
- Force Level Execution (FLEX)
- Joint Targeting Toolkit (JTT)
- Real Time C2 Decision Maker

SN- Real Time in Cockpit & Route RePlanning
- Expanded Situation Awareness Insertion (ESAI)
- Advanced SEAD Targeting (AT3)
- Integrated RTIC/RTOC for Combat A/C (IRRCA)
- Wind Tunnel Integrated RTIC/RTOC experiments & Demonstrations (WIRED)

HE- Human Interface
- Helmet Mounted Tracker and Display (HMT/D)
- Panoramic NVG-HUD with Symbology Overlay and Imagery Inset

MN- Weapons Integration- Standoff weapons
- Hammerhead - SAR Seeker A-G Missile
- Advanced Ground Attack Seeker
- Hypersonic Munitions Dispensing Weapon
- Multi-Sensor Modeling & Analysis

However, many fundamental issues still exist before such the initiative goals can be realized. The program was based on integrating stand-alone programs with specific objectives to meet the specific user program needs. The integration did not factor many of the critical infrastructure needs, which enable such a responsive system. These issues are the information network, access/sharing key information and planning data bases (both friendly and threat) and higher levels fusion, which turns data in information for all levels of conflict. Also the focus of the presented sensor to decision to shooter program was very platform/weapon centric. With that view, the operational advantage was focused on conflict area and not overall warfighter strategic issues. A more global look at the problem was needed to develop such a system to meet the challenge problem and gain the military global effect that the Air Force needed. In fact, the General Jumper's GSTF architecture added to the TCT timeline problem statement was my attempt to define the issue in such a context!

3.2 Supporting Program Reviews:

It turns out that IF had a number of other planned and ongoing programs, which addressed sub sets of the problem, outlined here in as well as attacking the critical infrastructure needs. These programs are sprinkled across the IF Divisions. Reviews of these programs were attended and the above problem statement defined to them as a challenge. The process was very informative and worthwhile. It was interesting to note that most programs had a narrowly scoped activity to meet specific user needs. In some cases this was totally justified as they were ACTD/ATD like activities which needed to produce specific products on well defined schedules. The tough step was to take the narrowly scoped program and leverage it into the larger problem. In any case it was very interesting to outline some of these interactions as a means to show lessons learned and possible changes to meet the larger issues.

3.2.1 GMTI

One of the first areas visited was the IFE well planned Ground Moving Target Indicator (GMTI) programs to get a first hand represented view of ongoing programs in the ISR information exploitation activities. The program area was well planned and well executed with full spectrum technology and operational activities included. It also included strong in-house as complementing contractual activities. Uniquely the in-house program was based on integrating a large collection of simulations from completed programs into a system design facility. The impressive part of the facility is that it was based on actual data to validate performance which in-turn was used to predict performance of planned tests or unique system configurations etc. This approach produced an expertise and capability well above any other competitor. Therefore, IF turned into the lead for this area as outlined in the attached roadmap Platform Independent GMTI capability -fig. 4-1.

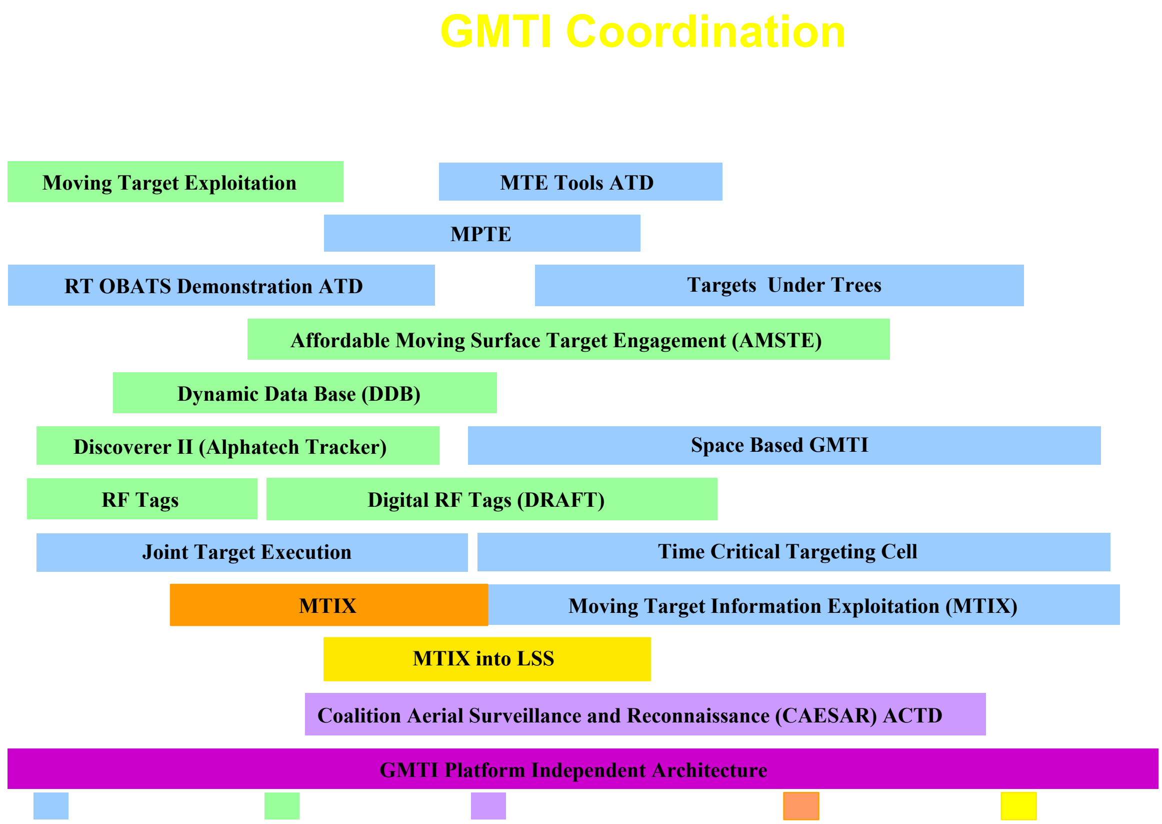


Figure 3-2 GMTI Coordination

User needs were demonstrated by obtaining technical leadership status and then obtaining funding from nontraditional R&D AF sources such as the DARPA funded Affordable Moving Surface Target Engagement (AMSTE) and the DOD funded Coalition Aerial Surveillance and Reconnaissance (CAESER) ACTD. The IFE GMTI team did an excellent job tying the current technologies to program needs. These two initiatives will be highlighted as they involve integration of GMTI into a more global system framework issue. In fact, the more Global issues are the areas that provide the greatest system insight.

3.2.1.1 AMSTE

The objective of the AMSTE program is to AMSTE will provide a new strike capability to rapidly engage moving surface threats from stand-off ranges, in all weather conditions, using affordable precision-guided stand off munitions. The AMSTE program is developing a network-centric targeting approach that will couple standoff airborne radar sensors and low-cost weapons in a real-time engagement network. Under the AMSTE approach, data from multiple airborne Ground Moving Target Indicator (GMTI) radar sensors are fused to provide weapons with real-time target position updates while in-flight. The activity is being developed to support a seamless moving target engagement from "nomination" through "track maintenance" to "engagement". The unique features include the development of precision fire control tracking algorithms, weapon data links, and system integration. The challenge is to maintain target ID through 20-30 minute engagement process allowing weapon delivery. The key technologies are the demonstration of a multi laterated geo registered GMTI sensor supporting fire control target tracking allowing precision track updates to weapons in-flight.

An onsite review of the program revealed that the program was well planned using the JSTARS platform as one of the GMTI sources and a BAC 111 outfitted with a second GMATI sensor. The radar system dwell was then optimized to provide added look time to allow accurate tracking and ID. The design was a reconstitution of designs from the early days of JSATRS under the Pave Mover/Assault Breaker program. (Circa mid 1970s). The critical enabling difference was the processing/computer capabilities of today and new tracking/ID algorithms. The intersystem communication was jerry rigged using available JSTARS downlink and then any available up link to weapons for testing. It worked fine for the testing but provided limited utility when factored into operational deployments (just like it did in 1970s).

The system used two weapon datalinks during the program: EPLRs for the JDAM drops and JTIDS for the JSOW drop. The program was able to send in flight target updates (IFTUs) at a rate of 5 Hz to the weapons. The IFTU WDL message itself was limited to less than 100 bytes. In the case of the JDAM drop nav corrections were sent at a 1 Hz rate. In FY03, EPLRS data links will be used for JDAM f weapon drop experiments. It will also use EPLRS as the inter-platform data link between the Joint STARS and BAC 1-11. UHF radios have been used for that function in the past.

The EPLRS is be used a stopgap measure for the program goals. It is not envision that it will be used as the future WDL if AMSTE is transitioned to the services. It is mostly used by the Army and is in a very crowded spectrum (the program has run into run into many frequency allocation issues during testing). It was used because it is a relatively cheap, compact units that fit nicely into weapons. This is not the case with JTIDS, which is what's recommended. The comment form program office were that " it would be extremely helpful to AMSTE if the services took on the challenge to develop and field a low-cost, compact JTIDS terminal or other JTRS compliant datalink."

3.2.1.2 CAESER

The other program that I focused on was the **CAESER ACTD**. It used the in-house IFE simulation testbed to design experiments, system architecture, develop test plans and interact in exercises. The actual field test programs was based on the use of simulations to develop the GMTI/SAR data base feeding appropriate distributed multi nation command centers/users. The focus of the program is the modern battle space where to operate effectively, commanders at all levels must “see first” and understand the battle space in order to act quickly and decisively. It is in this context that the CAESAR project was conceived to achieve operational and technical interoperability among systems participating in a coalition. The project is a co-operative effort of seven NATO nations (Canada, France, Germany, Italy, Norway, United Kingdom, and the United States). This program focused on the combined capabilities of the following GMTI/SAR-capable ISTAR platforms and their associated ground stations systems; HORIZON (France), CRESO (Italy), ASTOR (United Kingdom), RADARSAT 2 (Canada), JSTARS, U-2 ASARS-2A, ARL-M, Global Hawk (US). MTOC (Norway), IIES (Germany), SAIM (France), MATREX and MTIX (US) provide ground based exploitation capabilities."

The program objectives were well defined in a Coalition program as defined in the following excerpts from GMTI/SAR ISTAR Concept of Operations working paper:

- "Effective use of these assets will enhance situational awareness (SA) of surface operations and facilitate targeting. This will allow coalition commanders receiving this information to better understand the complex operational areas in a peacetime engagement such as a NATO PSO or a mid-to high-intensity conflict such as a NATO Article 5 operation. The requirement for timeliness of information to plan and conduct these operations can vary from near-real-time (NRT) to several hours or days depending upon the level of command, type of unit, and the nature of the operation."

- " Maximizing the use of scarce coalition ground moving target indicator/synthetic aperture radar (GMTI/SAR) capable intelligence, surveillance, target acquisition, and reconnaissance (ISTAR) assets is imperative. Elements of these systems include platforms (satellites, fixed and rotary wing, manned and unmanned aircraft), sensors and associated ground stations (GS). These elements must be integrated into a system of systems to meet the critical information requirements for complex operations. Achieving optimum results from low density, high demand (LD/HD) ISTAR assets require that the information initially gathered by these sensors is rapidly shared among all members of a coalition force."

- This GMTI/SAR system of systems is not a particular physical system; it consists of the protocols needed to integrate various national GMTI/SAR capable ISTAR systems so that their combined effectiveness is optimised. Integration is achieved at the GS level using existing communications and does not require dedicated hardware or personnel beyond that already supplied by coalition and national command HQ."

This program brings the difficult challenge of multiple users (coalition nations) together to share in a common information network. The last objective is one of the very hard driving technical challenges since requires establishment of common data format for GMTI/SAR data to operate over disparate existing communication channels.

The CEASER simulation was used in NATO exercise Clean Hunter 2001 to develop MTI and SAR data ground track data for ground vehicles. The aim of Exercise CLEAN HUNTER 2001 was to exercise and train units and NATO staffs in the orchestration and conduct of large-scale operations, within the constraints imposed by peacetime regulations. The CAESAR architecture enabled both raw and processed MTI and SAR data to be disseminated rapidly between exploitation workstation operators and between the operators and ISR coordinators/analysts, resulting in enhanced SA. This data was made available to the NATO ICC system through the use of Link 16 format messages. The Link 16 messages were used to represent Air Tracks and Ground Tracks. Link 16 is the equivalent of the US Tactical Digital (Data) Information Link - Joint Tactical Information Distribution System (TADIL-J). Potential targets for CAESAR sensors included:

* time critical targets and associated infrastructure;
* high value assets (TEL, bridging equipment);
* convoys of military vehicles;
* lines of communication (roads, rail, rivers, canals);
* rotary wing and low-slow flying aircraft; and
* traffic into, out of and around logistics, supply and tranship centres.

The exercise was well received and stressed the difficult multi nation information and control issues as well as the protocols and communication problems. The program develops work arounds that allowed the demonstration of the concept and obtain user support. The issue is to provide a design that includes flexibility to integrate into current warfighter systems using standard interfaces and networks.

3.2.1.3 LESSONS LEARNED

It took inventive system design strategies for these two programs to pull off successful demonstration. They each had to define user and source information needs and then detail approaches to meet integrated testing needs. The staff did a superb job integrating new capabilities into field demonstrations. A common area that required significant activity was the communication network issue. The issue was finding a network that would handle the format, amount of data needed with sufficient multi node connectivity. On top of that, limited bandwidth hurt accuracy performance by adding latency between information collected at geographically separated nodes. This latency made cross correlation and cueing difficult. The program review meetings were focused on these communication issues with contractor and multi national members working out a reasonable network solution. The shortfall was that the development of field transitionable communication designs was not developed. These designs must allow common message standards at flexible data rates to be used among system members, while meeting weapon system form/fit/function issues at a cost allowing use in large platforms as well as weapon systems. The weapons system data link issue has been a long time problem. The communication requirements for CAESER are provided in Appendix A. It was excised from a CAESER architecture study activity!

Providing a data link which meets differing weapon needs in a common link design at low costs <2K has been a long standing challenge. Finally and not leastly the overall data link framework must allow multiple users and varying data rates which can be traded against anti-jam/covert link capabilities. The JTIDS (TADIL J) format was used to satisfy parts of the experiments. It was initially design to meet many of these issues. However, the units are too costly and provide limited (128kb/s per net) data handling capabilities.

3.2.2 Target Under Trees (TUT):

AFRL has put together a multi directorate initiative to address the time critical targeting issue of targets masked by foliage cover. The program has it's foundation in the requirements of CSAF tasking to develop “70%” solution for finding/identifying/engaging deep hide/CC&D targets (e.g., targets under trees) by assessing “low hanging fruit” in the technology base which could provide significant capability in minimum time. The assessment team included DARPA, ACC, AC2ISRC, ASC, ESC, and AAC. The challenge is to demonstrate and quantify the capability to find, identify and engage time-critical targets (TCTs) in difficult conditions.

The program approach was based on the introduction of new foliage penetrating radar integrated via fusion with other observables to provide a demonstrable capability. The sensor thrust is based on a family-of-systems approach combining new and existing sensing capabilities. Specifically, Very High Frequency (VHF) Foliage Penetration Radar with Change Detection processing for concealed target detection. This will be augmented by fusion of information from new and existing sensors for target location and identification (IMINT, SIGINT, GMTI, FOPEN CD, and MASINT). Decision aid will be developed for human decision-makers based on high confidence identification. The end game will use height of burst fusing for greater lethality against targets deployed in foliage. The first half of the program is focused on technology capture, maturation and integration. Principal technology capture is foliage penetrating radar from the DARPA/Army/AF FOPEN program. Principal technology maturation thrust is in intelligence fusion across INTs, space and time. Second half of the program is focused on working with users at exercises to tailor the TUT family of systems to meet users’ end-to-end kill chain needs. The TUT development program is leveraging existing/legacy systems to the maximum extent possible to allow new technologies to be fielded quickly. The two driving technologies are foliage penetration (FPR) SAR imagery/exploitation and automatic intelligence fusion. FPR SAR provides a major improvement in finding concealed targets. TUT is developing a change detection reporting capability that will provide automatic first level exploitation of the FPR SAR imagery. This reduces operator loading while improving overall quality. The automatic data fusion will allow an operator to accurately handle today’s high input data rates. The IFS (Intelligence Fusion System) will be able to automatically fuse information from different sensors thereby providing an operator the ability to review the data at a high or low level. The TUT program is leveraging the TES family of systems programs and JSWS development to provide a quick path for fielding new technologies. The objective FPR sensor platform is the Global Hawk. The RC-12 aircraft is a test bed that is being used for a proof of concept. The FPR ground station will be transitioned into the Global Hawk ground station.

Technology availability date is late FY04 to early FY05, based on live demonstrations at exercises and operational scenario effectiveness from modeling and simulation. Technologies are planned to transition through multiple SPOs (ESC – automated fusion, ASC – FOPEN radar, AAC – height-of-burst fuze). The payoff to the Air Force is to deny sanctuary to ground mobile targets by providing enhance sensing integrated into the current C2 ops process. However, the system transition issues in this program are uniquely similar to the issues outlined in both AMSTE and CAESER programs. In fact, in most cases are planning to use the same network.informations assets. So it is even more critical to take on this problem from both the data and network distribution view.

3.2.3 Distributed Tactical Information Grid (DTIG)

The objective of this approved AF ATD program is to develop communication information technologies to support seamless enroute/in-theater information infrastructure for the warfighter. DTIG would be a deployed subset of the overarching DoD Global Information Grid (GIG). The DTIG would operate as a rapidly deployable, mobile, information dissemination grid generating increased combat power through information superiority by seamlessly integrating networks, sensors, decision-makers, and shooters. DTIG organizational flexibility and worldwide addressability would enable commanders to dynamically plug and play sensors, engagement systems, weapons, command and control, and support capabilities into task-oriented combat packages across a theater. Improved warfighter effectiveness would result from shared awareness, increased speed of command, higher tempo of operations, greater lethality, increased survivability and a significant degree of self-synchronization. The vision for how the Air Force would use DTIG to support the information needs for force projection and the Expeditionary Aerospace Force (EAF) 10 to 25 years in the future is documented in the "Air Force Concept of Operations for the Deployable Theater Information Grid" CONOPS

The focus technical areas include: 1) a theater-wide open layered architecture 2) self-organizing, mobile wireless IP networks with global addressing and Quality of Service (QoS) mechanisms 3) wideband communications links with low probability of interception/detection (LPI/LPD) 4) communications / information gateways. The ddevelopment will follow four main tracks: communications links associated with a theater-wide airborne broadband network backbone; communications links associated with mobile subscriber access to the network backbone; gateway technology for providing

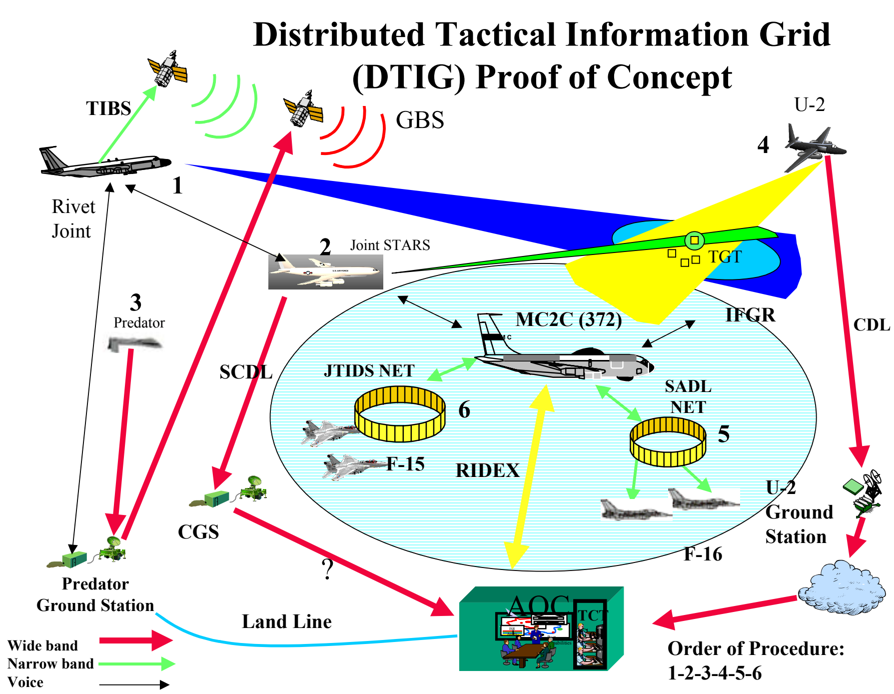


Figure 3-3 Distributed Tactical Information Grid (DTIG) Proof of Concept

internetworking of legacy theater communications & network systems as well as reachback to the Global Grid infrastructure; and a common set of network protocols enabling seamless internetworking of theater broadband and extension networks. The broadband communications link components will leverage large ongoing military and commercial developments in this area such as the DOD's Common Data Link (CDL) technology and/or commercial phased array technology (the ATD would make modest investments in communications link development(s) to be selected as the result of an open solicitation). The gateway component will leverage ongoing developments in this area such as Anzus Corporation’s Rosetta technology. The network protocol suite will be IP based, leveraging COTS/GOTS Internet technology developments and providing open systems network architecture that enables internetworking with the vast majority of communications networks worldwide. Open systems architecture will also be a critical enabler for seamless and efficient incorporation of emerging technologies. DTIG will provide support for voice, video, data, and Web services as well as more advanced information management and information fusion capabilities. This program has the promise of satisfying many of the communication issues outlined above. It provides a well-defined means of tying the various networks together allowing transition of the newest and best sensor and C2 designs. It also provides a means to be backward compatible with currently used Comm protocols and designs while pushing the network forward to more powerful anti jam/LPI networks as detailed in the CDL program.

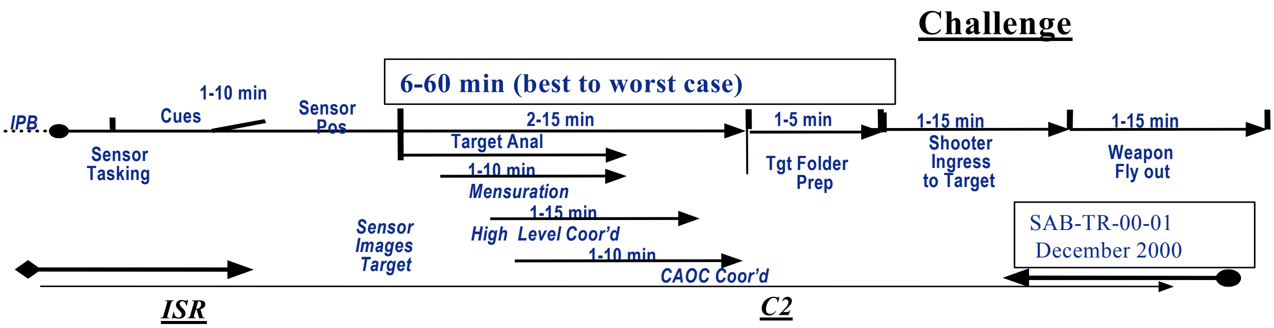
A missing ingredient in the program is the tie to users as demonstrated in the AMSTE & CAESER. The issue here is designing the system against the timewise loading issues that a system problem develops. If this is not accomplished the Comm program develops a pipe, which although flexible may not be responsive. Numerous meetings were establishes between these program leaders and better understanding of specific needs developed. In fact, joint program activities proposed which are still in planning stages. This problem is outlined in figure 3-4. In this initial cut at a system (Comm + user design) the nodal wiring diagram was married with sensor/exploitation scheme (note order of precedence) to develop a baseline for integrated performance measures. The order of precedence design uses passive Rivet Joint detection's as the initial tip off of an event (it also provides some measure of ID). That info is then used to cue Joint Stars, predator and U2 to add additional GMTI and SAR/Picture info. This data is then shared using fusion algorithms around the network to develop a strong track, ID and targeting all shared with AOC planning process. The DTIG network allows the process to happen and develops connectivity with bandwidth and message structure-translation. Finally, the DTIG net provides the connectivity to the weapon system and pipes to collect BDA. In the middle of the picture is the MC2C aircraft as a holder to show how this forecasted capability could be used in a network configuration. Also, it sets standards for the function of a/c in terms of sensor, C2 or networking mission of such a future weapon system.

The importance of these interactions was not only understanding between IF program offices but also a framework to further exchange program details and requirements allowing transition to the AF. A unique outcome was that most of the sensor, fusion, exploitation and network capabilities currently exist in hardware or simulations within the IF onsite laboratories. It provides a means to drive the system issues of the problem. Further, it provides a means to take on the larger AOC C2 issues involved with Predictive Battlespace awareness, targeting, predictive planning/replanning, and Effects

Based Operations. All of the key ingredients are available to develop scenarios, tradeoff system performance to meet decision-maker needs.

4.0 Required Changes

The review of the IF programs provided valuable insight into the problem. The programs reviewed provided a representative view of the issues to be addressed. This view has been shared and significant progress has been made developing cross IF Division interactive development strategies. As close to this report I would like to use this result as a technical guide required to changes needed in C2 systems to move from the NOW capabilities to the FUTURE in the initial challenge problem. This recommendation is outlined in Figure #4-1. As noted earlier, this challenge presents a daunting challenge for C2 Systems Design that has as its foundation a flexible communications infrastructure that allows integration of fusion/decision making/planning technologies to address the TCT problem. The fundamental issue is to integrate theater assets in an IP based structure that allows data sharing approaches to ISR, decision-making, and execution or targeting information. Thus, the information can be managed optimally to meet the needs of the system/network rather than specific sensor/radio/subsystem needs. Developing network architecture is a difficult task. This architecture must embody the interaction among ISR assets to provide high confidence detection, tracking and targeting within TCT time frame allocated for this function. This function must be performed in light of the ongoing planning, decision making and execution functions not as separate - here is a target then so what should we do now. Establishing a network controller is a critical step in meeting diverse information needs. The network controller integrates quality of service judgments based on available information and requirements, attributes of available data, processing power of the fusion/decision making algorithms and information that is already available to members of the network. Further, the network can be leveraged to obtain and process information needed to implement Effects Based decision making tradeoffs as well as supporting Effects Based targeting/retargeting. This approach also establishes the means to transition technology in implementation spirals with a well developed interfaces and architecture.



Data Based
- **Collapsed Time Frame**
- **Integrated Sensor Operations**
- **Integrated Exploitation/ID/Tracking**
- **Info Based Signal Processing**
- **Multi Int Fusion**

Ops/BM Based
- **Quick Strike Decisions Proc.**
- **C2/ISR Coord Needed**
- **IPB/Sensor Tasking Needs to Include C2 Planning Issues**
- **Integrated Operations Throughout Mission Req.**
- **Capability Transition to Current BM system Req.. CAOC-X**

Comm
- **Enhanced Data Links (Network, WB, Wpn)**

Figure 4-1 TCT Technology/ System Integration

5.0 Recommendations

The development of an approach to satisfy the TCT challenge must be both evolutionary and revolutionary in scope. The issue is to leverage current capabilities while developing a technological and capability rich environment. This approach appears to be well accepted by the Air Force and endorsed by the transition mechanisms being established in Air Force initiatives such as JEFX. Figure #5 represents an accepted baseline approach for satisfying the TCT activities. In partitions the problem into technical and capability areas which can be developed but with well be architecture interactions.

The ISR functions are handled in terms of sensor capability, planning functions and decision needs to satisfy critical mission needs. Therefore strong interactions are needed between the Battle Management functions and sensor/sensor fusion function as outlined in Attack Ops sub sections of figure #5. This the sets up a framework to determine the sample data structure to find critical path through the available info data bases such as: Intelligence Preparation of Battlefield (IPB) function (provides enemy capabilities), Joint Targeting Toolkit (JTT) function (prioritizes targets) and real time ISR data which leads to responding to time critical targets.

Using this approach then technology can be mapped into system needs as outlined in figure #5. The developments are then coordinated to the user needs, system architecture and inter-technology capabilities. Further it provides a means to develop testing methods which are focused on the problem rather than the technology subsystems.

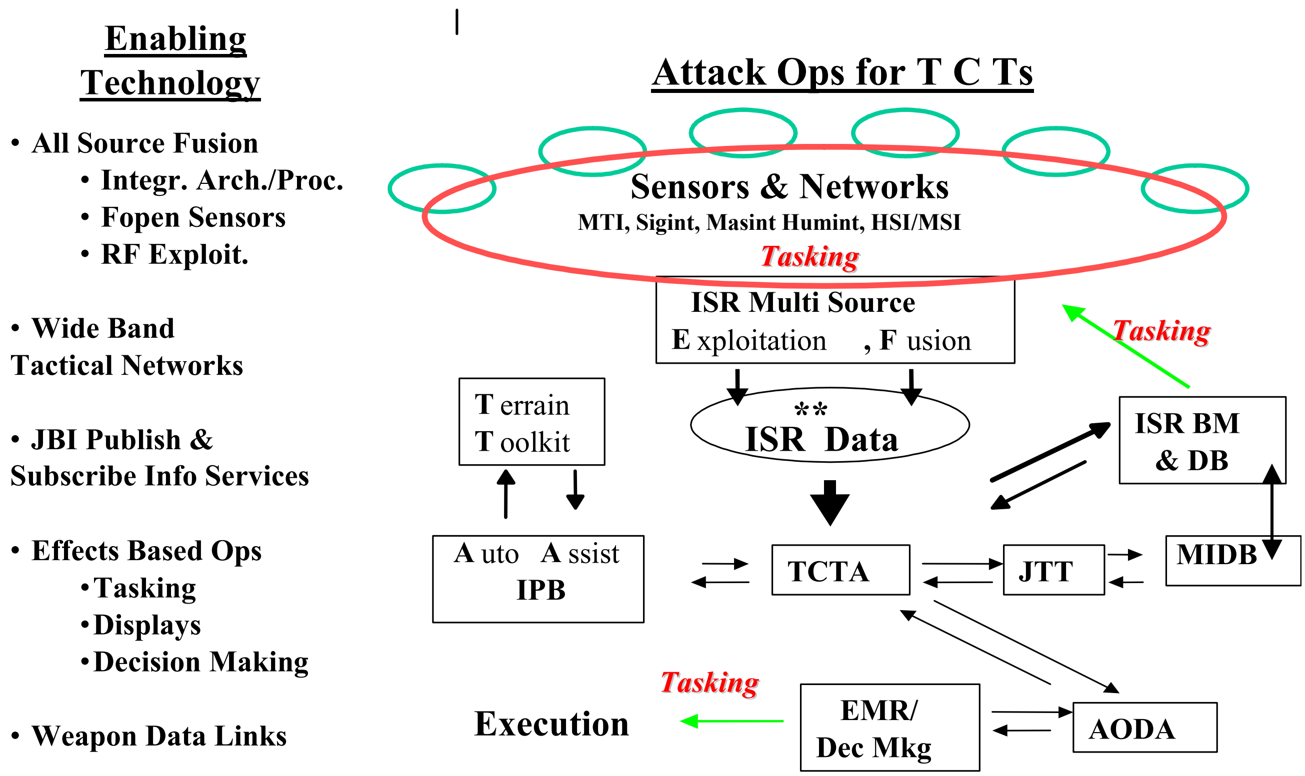


Figure 5-1 C2ISR Network

An area that needs some additional attention is the information infrastructure needed to support this system concept. This infrastructure needs to be based on well-established network technology as embodied in IP addressing methods. In this way the assets working together in an tactical theatre can interact between each other as well as allow other remote command authorities assuming one member of the network is visible to a ground node for distribution via available communications infrastructure. Further the members of the tactical network, even if they're using different network structures (JTIDS, SADL, MilSATCOM, Common Data Link, etc) can readily interact. In this way the network of assets can interchange data, needs, and capabilities towards a common challenge. The approach recommended will be based on using a wideband network to link all the assets together. Translators between the other available networks will augment this. The wideband network will provide the IP connectivity to the ground. Since all assets, especially the wide body assets (AWACS, Joint STARS, U-2, Rivet Joint) will have this capability all that is needed is one of these assets to have line of sight to the ground for all the network assets to have connectivity. This concept is outlined in figure #5-2.

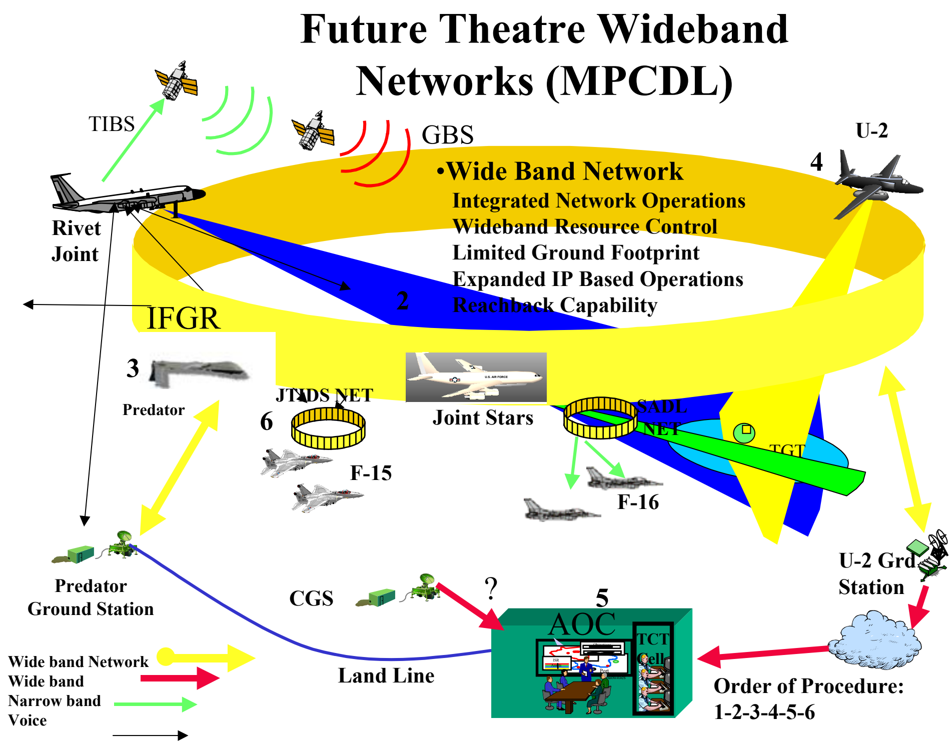


Figure 5-2 Future Theatre Wideband Networks (MPCDL)

6.0 Summary:

It is therefore recommended that a network centric approach be undertaken. It satisfies the user needs, links TCT and GSTF needs, provides readily transitionable products but also allows focus of these various technology thrusts to end user needs. To this end the following approach is recommended:

1. Start by using a System/Spiral Approach for Development of Integrated C2 Products - Consider all issues in he design from sensor to decision-maker and project needs throughout process in terms of SOA capabilities. For example, how would JBI revolutionize the process?
2. Use Warfighter Stated Objectives as Cornerstone
3. Map Technology Capabilities to Warfighter Objectives- Showing Capabilities and Limitations in Terms of Thrusts and Payoff
4. Establish a System Based Framework & Challenge Problem for the Warfighter
5. Theatre Info to Interface with IP Based world
6. Focus on Comm Infrastructure Architecture which unifies approach(e.g. IP Based Leverage Architecture) to:
    - Develop C2 Decision Making Products via Effects Based Manipulation of Fused Data Sources
    - Allow Timely Integration of Planning and Logistic Cycles & Products

7. Establish a technology/development configuration lead and cross thrust program within the Lab
    - Provide Integrated Lab Wide Approaches
8. Develop close ties with customers: Users, Related Subsystem Developers (Sensors, Weaponeers, Human factors)
9. Establish a Common Framework for Demonstrations/ Transition of Technology: Then Spiral Transitions Products

One final note, the area of Decision Science and Military Science needs some special attention. The military science field is reasonably well defined based on research, studies, field operations and historical database. Similarly the area decision science has a strong foothold in consumer based issues. The question when designing a military system is what is needed where to allow decisions under uncertainty but allow flexibility given the changing face of a battle. It is also recommended that this area become a focus area to bound the C2 System structure.

7.0 Conclusion:

A wealth of research and technical capabilities exists within the AFRL/IF directorate to counter the TCT problem in a GSTF environment. The Directorate is already moving towards integrating technology demonstrations, which leverage these technologies to a common system design. A continued focus on this approach is needed along with a strong research program, which attacks the hard issues allowing the development of a way ahead. The hard problem is focusing program thrusts on results that are naturally extendable as technology grows. System design issues need to be factored in program strategies. To this end, it may be necessary to have a senior overview staff whose sole responsibility is projecting needs, growth and reasonable program approach to assure spiral transition to projected system issues. This group could be made up of members from each directorate with a lead in IFS. Taken to the limit, programs will need to be passed by this group before major milestones can proceed. The issue is to encourage cooperative programming and technology to programs that meet future capabilities and present a strong unified thrust. It also may provi8de a means of planning in terms of what is missing.

Appendix A

Rule of Thumb" Estimate for GMTI-related Communications

The communications bandwidth requirement for GMTI data is a function of the number of movers, the average revisit rate, and the size of the GMTI data packets.

- The OWG has informally estimated the maximum number of movers that would be expected to oppose a friendly Corps to be roughly 30,000 movers in their AOR.
- There are 32 bytes per GMTI in the NATO EX format. However, additional bytes must be included to account for the headers added to packets by the different layers of the network protocols. Joint STARS data indicates an average of about 45 bytes per GMTI.
- The revisit rates vary by platform and situation. However, a 40-second revisit rate seems reasonable for estimating purposes.

Multiplying the number of movers (30,000) by the number of bytes/mover (45) and by the number of bits/byte (8) yields a total of 10,800,000 bits that might be moved every 40 seconds. Dividing this amount by 40 seconds yields a sustained data rate of 270,000 bits per second, or 270 Kbps *as a theoretical upper limit* (i.e., if a GMTI sensor could observe the entire AOI, see every mover, and had adequate communications to download the data to a ground station).

This is an *estimated* upper limit that must be compared to the *observed* maximum burst rates for HORIZON and Joint STARS. As previously noted, the maximum HORIZON burst rate was approximately 140 Kbps and the maximum Joint STARS rate was approximately 400 Kbps. It was also noted that the maximum burst rate for the HORIZON simulator was 360 Kbps.

"Rule of Thumb" Estimate for SAR-related Communications

The communications bandwidth requirement for SAR images is a function of the frequency of images and the size of the images.

- The Joint STARS images averaged about 1.2 MBytes.
- RADARSAT images are significantly larger. Also, other sensors (e.g., Global Hawk) have finer resolution than Joint STARS and will produce larger image files. Unfortunately, Global Hawk has not participated as a live-fly asset in CAESAR exercises, so there is no "real" information available on message size or frequency. For estimating purposes, the larger images are assumed to be 250 Mbytes on average.
- The Joint STARS images were sent quite often during one day of SR02, on average one image per 100 seconds (but with a large standard deviation), and less frequently on another day (one every four minutes).

- The number of RADARSAT images per day varies depending on the latitude of the AOI. In northern latitudes, for example, RADARSAT may fly over a region three times a day. In more southern latitudes, it may fly over a region only once every three days or so.
- The frequency of images from other sources (e.g., U-2) is not known.

For small images, multiplying the number of bytes per image (1,200,000) by the number of bits per byte (8) yields a total of 9,600,000 bits to be moved every 100 seconds. This yields a sustained data rate of 96,000 bits per second, or 96 Kbps for small images.

For the large images, multiplying the number of bytes per image (250,00,000) by the number of bits per byte (8) yields a total of 2,000,000,000 bits that have to be moved for every image. If a large image arrived every 100 seconds this would result in a sustained data rate of 20 Mbps just to keep up!

Looking at a large SAR image from a communications perspective, if a sustained 1 Mbps line was available, it would take more than 33 minutes to send a 250 Mbyte image. Clearly there will have to be some measures taken to control or adjust the dissemination of large images across the network. For example, it may be possible to "chip" large images and send only a small area of interest in maximum resolution.

The estimated sustained data rates above must be compared to the maximum *observed* bursts of 600 Kbps for Joint STARS images at SR02.

The Bottom Line: Total Communications Requirements

Without the capability to buffer messages and throttle their injection onto network links between a source and a destination, each link must be able to keep pace with the maximum burst rates of the sources. Otherwise, data will be lost. Further compounding the problem is that sometimes the bursts from the different sources will overlap and other times they will not. To bound the bandwidth requirements, it is necessary to consider the ideal case (i.e., no overlapping bursts) and the worst case (i.e., all bursts overlap).

Ideal case: No overlapping bursts

Under the ideal case, there will be no simultaneous maximum bursts of data. Therefore, the maximum bandwidth requirement would correspond to the largest burst. Here the winner is the Joint STARS SAR image with a burst rate of 600 Kbps.

Is this a reasonable estimate? Well, the average GMTI data rates for HORIZON and Joint STARS are around 20 Kbps each. Therefore, 400 Kbps bursts should be relatively infrequent. We also know that a 1.2 MB SAR image would take 16 seconds at 600 Kbps. The frequency of the Joint STARS images ranged between 100 seconds and four minutes. So SAR image overlaps should also be relatively infrequent at 600 Kbps. However, a SAR image would likely overlap with GMTI data so a more reasonable lower bound would be the sum of the maximum GMTI and SAR burst rates.

Combining that the maximum GMTI and SAR burst rates yields a total of 1 Mbps, or roughly the equivalent of a T1 line.

This data rate *may* result in some data loss if no data buffering or throttling mechanisms are employed. It also does *not* include the transmission of large (250 Mbyte) images.

Note: As of this writing the NC3A has begun a program of network modeling. Preliminary results presented at the January 2003 CAESAR working group meeting confirm that a 1 Mbps pipe is adequate for GMTI and SAR data dissemination (SR02 model). The modeling effort will continue with some additional configurations examined and the results will be included in subsequent versions of this report.

Worst case: All bursts overlap

If the desire is to ensure that absolutely no data is ever lost, then the total communications bandwidth must be the sum of the maximum bursts of each source.

If we assume that all GMTI sources have a maximum burst rate of 400 Kbps then the total bandwidth required for GMTI is 400 Kbps multiplied by the number of GMTI sources. For an exercise that includes ASTOR, CRESO, Global Hawk, HORIZON, Joint STARS, Predator, and U-2 that would require 2.8 Mbps for GMTI.

If we assume that all SAR sources have a maximum burst rate of 600 Kbps then the total bandwidth required for SAR is 600 Kbps multiplied by the number of SAR sources. For the above example, that would be 2.4 Mbps for SAR images.

Combining the GMTI and SAR requirements yields a total of 5.2 Mbps.

This data rate should result in little, if any, data loss for GMTI and small images. However, it also does *not* include the transmission of large (250 Mbyte) images.

Ways to reduce the bandwidth requirement

There are actions that can be (and are being) taken to reduce the bandwidth requirements associated with the above examples.

- The sensor data sources can throttle the rate at which they inject data onto the network. For example, the Joint STARS downlink to a ground station operates at a maximum rate of around 20 Kbps. JSWS is currently being modified to make the injection rates for the Joint STARS messages a “tunable” parameter for the JSWS operator. Therefore, JSWS will be able to throttle the injection rate to make it comparable to the rate it receives the messages, or a slightly greater rate. The Joint STARS simulator (VSTARS) injects messages at only 20 Kbps because it emulates the Joint STARS down link. Similarly, the HORIZON real and simulated data could be throttled back to eliminate the large bursts.
- Buffering devices could be used between high speed networks and slower links to capture the “bursts” of data and feed them onto the slower lines at rates they can handle. If the buffers were large enough, the slower links would only have to carry the sum of the average data rates from the sensor sources. Packeteer was used on some links during Clean Hunter and Strong Resolve for this purpose. However,

Packeteer has a limit of 10 seconds of buffering, which may be adequate for GMTI in most instances but is not adequate for SAR messages.

- For the large images (250 Mbytes) mechanisms *must be found* to reduce the size of the files or very high-speed data links will be required between nodes.
- The CAESAR Shared Data server could be used to reduce SAR data bandwidth requirements. For example, it could provide services to chip out portions of large images and to provide warnings to a requestor that a large image will take a long time to download.
- Large images could be given the lowest priority for transmission so that high-priority GMTI, SSRs, free text messages and smaller images are not delayed. This would have to be done in concert with a buffering mechanism. The large images would effectively be transmitted only as bandwidth becomes available.

If these adjustments are made, the bandwidth requirements could be greatly reduced. Assuming an average rate of 30 Kbps for each MTI source, then the bandwidth requirement in the previous example would be 210 Kbps. Assuming a rate of 80 Kbps for SAR sources (1.2 Mbyte per image) yields a requirement of 320 Kbps for SAR.

This would reduce the overall bandwidth requirement to about 530 Kbps.

Potential impact of the CAESAR Shared Data

The final caveat that must be mentioned is that these estimates do not include any additional loads that will result from queries to the CAESAR Shared Data server. If the queries are made from a workstation that resides on the same high-speed LAN as the server, then there should not be a noticeable impact. However, if the workstation and server reside on a low-speed network (e.g., 10 Mbps), or a low-speed line connects a remote workstation, then the bandwidth requirements will have to be adjusted accordingly.

__Section Summary__

The Table 6-1 summarizes the bandwidth requirements for a typical, large-scale CAESAR exercise.

Table 6-1 CAESAR Bandwidth Requirements

	Unconstrained data injection	**Constrained data injection***
Some packet loss	1 Mbps	530 Kbps
No packet loss	5.2 Mbps	530 Kbps

* Throttling data at source or providing store and forward capability for slower links.